

# Franck-Condon Factors to High Vibrational Quantum Numbers IV: NO Band Systems

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Franck-Condon factor arrays have been computed numerically to highest known vibrational quantum numbers for the following NO band systems.

$\beta$  : (B<sup>2</sup>II–X<sup>2</sup>II)      Feast 1: (D<sup>2</sup> $\Sigma^+$ –A<sup>2</sup> $\Sigma^+$ )  
 $\gamma$  : (A<sup>2</sup> $\Sigma^+$ –X<sup>2</sup>II)      Feast 2: (E<sup>2</sup> $\Sigma^+$ –A<sup>2</sup> $\Sigma^+$ )  
 $\delta$  : (C<sup>2</sup>II–X<sup>2</sup>II)      Ogawa 1: (B'<sup>2</sup> $\Delta$ –B<sup>2</sup>II)  
 $\epsilon$  : (D<sup>2</sup> $\Sigma^+$ –X<sup>2</sup>II)      Ogawa 2: (b'<sup>4</sup> $\Sigma^+$ –a<sup>4</sup>II)  
 $\beta'$  : (B'<sup>2</sup> $\Delta$ –X<sup>2</sup>II)      "M": (a<sup>4</sup>II–X<sup>2</sup>II)  
 $\gamma'$  : (E<sup>2</sup> $\Sigma^+$ –X<sup>2</sup>II)

## 1. Introduction

The NO molecule has a rich spectrum of electronic transitions which extend from the vacuum ultraviolet region into the infrared. In addition, a vibration-rotation spectrum in the infrared is well known. The disposition of energy levels and transitions between them have been extensively studied by Miescher [1962 and references therein] and many others. A partial energy level diagram is displayed in figure 1, and transitions are indicated on it which give rise to the best known band systems which are treated in this paper. The NO molecular spectra have important applications to a wide range of chemical and physical situations of contemporary interest; for example, radiation from hot air and chemiluminescent gas reactions.

It is well known that the Franck-Condon factors  $q_{v'v''} = |\int \psi_{v'} \psi_{v''} dr|^2$ , which are the squares of the overlap integrals of vibrational wave functions, exert a dominating and proportional influence on intensity distributions of molecular spectra [Nicholls and Stewart, 1962]. It is thus the purpose of this paper to present tables of Franck-Condon factors (calculated on the basis of the Morse model) for the NO band systems listed in table 1.

TABLE 1. *Band systems treated*

NO $\beta$ (B <sup>2</sup> II–X <sup>2</sup> II)	NO Feast 1 (D <sup>2</sup> $\Sigma^+$ –A <sup>2</sup> $\Sigma^+$ )
NO $\gamma$ (A <sup>2</sup> $\Sigma^+$ –X <sup>2</sup> II)	NO Feast 2 (E <sup>2</sup> $\Sigma^+$ –A <sup>2</sup> $\Sigma^+$ )
NO $\delta$ (C <sup>2</sup> II–X <sup>2</sup> II)	NO Ogawa 1 (B' <sup>2</sup> $\Delta$ –B <sup>2</sup> II)
NO $\epsilon$ (D <sup>2</sup> $\Sigma^+$ –X <sup>2</sup> II)	NO Ogawa 2 (b' <sup>4</sup> $\Sigma^+$ –a <sup>4</sup> II)
NO $\beta'$ (B' <sup>2</sup> $\Delta$ –X <sup>2</sup> II)	NO "M" (a <sup>4</sup> II–X <sup>2</sup> II)
NO $\gamma'$ (E <sup>2</sup> $\Sigma^+$ –X <sup>2</sup> II)	

Note: (1) See Peyron and Broida (1960).

This paper is one of a series which treat astrophysically and aeronomically important band systems. Earlier papers have treated O<sub>2</sub> Schumann-Runge [Nicholls, 1960], N<sub>2</sub> and N<sub>2</sub><sup>+</sup> transitions [Nicholls, 1961], Oxides [Nicholls, 1962a], Vacuum Ultraviolet transitions [Nicholls, 1962b], CO<sup>+</sup> tran-

sitions [Nicholls, 1962c], I<sub>2</sub> [Nicholls, 1963], CN transitions [Nicholls, 1964a]. Papers are in preparation on O<sub>2</sub>, C<sub>2</sub>, and H<sub>2</sub> transitions.

## 2. Method

Details of the method of computer calculations of the Franck-Condon factor arrays have been discussed in earlier papers of this series (see e.g., Nicholls 1961). The input data are  $\omega_e$ ,  $\omega_e x_e$ ,  $r_e$ ,  $\mu_A$ ,  $v_{\max}$  for each electronic state involved and a Morse model is assumed for the potential. This is admittedly an empirical expedient but is adequate in many cases.  $v_{\max}$  values appropriate to the spectroscopically highest known levels as summarized in Wallace's [1962] compilation and Pearse and Gaydon's [1963] compilations and in the original papers listed therein, have been adopted.

The input data used in the calculations (which were performed on the IBM 7094 computer in the NBS Computation Center), and the sources of these data are summarized in table 2.

TABLE 2. *Basic data*

State	$\omega_e(\text{cm}^{-1})$	$\omega_e x_e(\text{cm}^{-1})$	$r_e(\text{\AA})$	$v_{\max}$	$a_e(\text{cm}^{-1})$	$B_e(\text{cm}^{-1})$	Reference
X <sup>2</sup> II	<sup>1</sup> 1903.85	<sup>1</sup> 13.97	<sup>1</sup> 1.1508	23	<sup>1</sup> 0.018	<sup>1</sup> 1.707	[1]
A <sup>2</sup> $\Sigma^+$	2374.8	16.46	1.0637	15	0.0192	1.9972	[2]
B <sup>2</sup> II	1037.69	7.603	1.415	19			[2]
C <sup>2</sup> II	2395	15	1.062	4	0.03	2.002	[3]
D <sup>2</sup> $\Sigma^+$	2323.9	22.885	1.062	11	0.021	2.0026	[2]
E <sup>2</sup> $\Sigma^+$	2373.66	15.87	1.066	5	0.0182		[4]
B' <sup>2</sup> $\Delta$	1216.6	15.88	1.303	6	0.109	1.33	[5]
b' <sup>4</sup> $\Sigma^-$	1168	13.3	<sup>2</sup> (1.300)	3	<sup>2</sup> (0.02)	<sup>2</sup> (1.335)	[6]
a <sup>4</sup> II	1019	12.8	<sup>2</sup> (1.407)	3	<sup>2</sup> (0.02)	<sup>2</sup> (1.14)	[6]

$\mu_A = 7.46881$  for all states.

Notes:

<sup>1</sup> Average value of two components of the doublet state.  
<sup>2</sup> See text for discussion of these data.

References:

- [1] Ogawa (1955).
- [2] Barrow and Miescher (1957).
- [3] Lagerqvist and Miescher (1958).
- [4] Feast (1950).
- [5] Miescher (1956).
- [6] Ogawa (1954).

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In the case of the  $b^4\Sigma^-$  and  $a^4\Pi$  states, Ogawa [1954] gives  $\omega_e$  and  $\omega_e x_e$  values but not  $r_e$  values. In order to obtain  $r_e$  values for these states, recourse had to be made to an iteration method previously used by Nicholls, Fraser, Jarman, and McEachran [1960] which involves the use of Pekeris' [1934] relation

$$B_e = \frac{1}{\omega_e x_e} \left[ \frac{\alpha_e \omega_e}{6B_e} + B_e \right]^2 \quad (1)$$

where the symbols are as defined by Herzberg [1950]. Some knowledge of the  $\alpha_e$  values for the  $b^4\Sigma^-$  and  $a^4\Pi$  states is required before eq (1) may be used iteratively to determine the  $B_e$  values and thus, the  $r_e$  values from eq (2)

$$B_e = \frac{h}{8\pi^2 c \mu r_e^2} \quad (2)$$

It is clear from table 2 that  $\alpha_e \sim 0.02 \text{ cm}^{-1}$  for most of the NO states. Further, the close similarity between the structure and energy level array of NO and  $O_2^+$  pointed out by Vanderslice, Mason, and Maisch [1959], and the close equality between  $\alpha_e$  values for all  $O_2^+$  states, including  $b^4\Sigma^-$  and  $a^4\Pi$ , led to the adoption of  $0.02 \text{ cm}^{-1}$  for the  $\alpha_e$  values of the corresponding NO states. The  $B_e$  values for the  $O_2^+$  states were then respectively used as starting values for the iterative use of eq (1). A very few (3 or 4) cycles of iteration were then required before convergence was respectively obtained to the  $B_e$  values listed in table 2 for these states.

### 3. Results

Franck-Condon factors for the band systems listed in table 1 are displayed in tables 3-13. The Condon loci are clearly indicated on them by setting the local maximum values in boldfaced type. In each of the tables, the negative number in each entry is the power of ten by which the entry is multiplied.

### 4. Discussion

The Condon loci of tables 3-13 agree closely in each case with the commonly observed distribution of emission bands where they are known. [See Wallace 1962, and Pearce and Gaydon, 1963].

Franck-Condon factors for a few bands on the primary locus of some of the systems treated in table 3-13 which contribute to the absorptivity and emissivity of heated air have been discussed recently [Nicholls, 1964b] with other similar data of aeronomically important spectra at the Aeronomy Symposium on Laboratory Studies held at the International Association of Geomagnetism and Aeronomy meetings, Berkeley, August 1963.

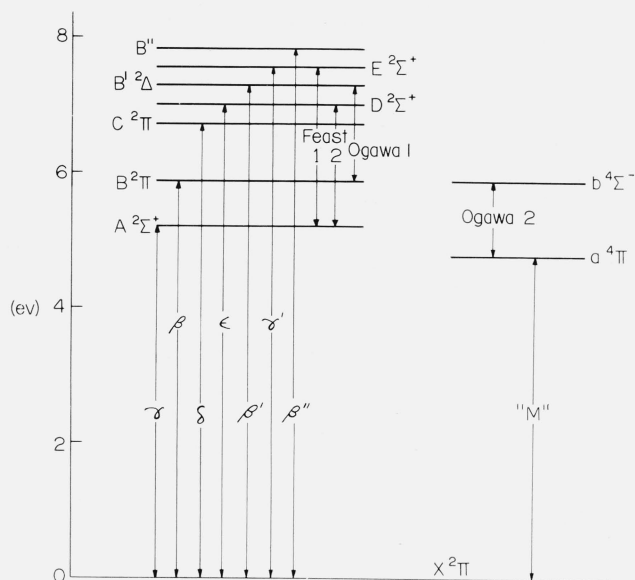


FIGURE 1

Previously published arrays for the  $\beta$  and  $\gamma$  systems [Nicholls, 1961] are here extended to higher quantum numbers using better constants. They are in good agreement with the recent calculations of Öry, Gittleman, and Maddox [1964]. Marr [1964] has recently used these data in a critical discussion of NO  $\beta$  and  $\gamma$  band strengths and his conclusions have been reviewed by Nicholls [1964]. Öry [1964] has recently reported NO  $\delta$  and  $\epsilon$  arrays which agree well with the more extensive ones presented in tables 5 and 6. An interpolation procedure, which will be discussed in detail elsewhere, has recently been set up, using the data of this paper and others reviewed in section 1, has recently been developed which allows interpolation of Franck-Condon factors (to moderate quantum numbers) for systems for which arrays have not yet been calculated.

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TABLE 3. *Franck-Condon factors to high vibrational quantum numbers for the NOB (B<sup>2</sup>II—X<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	2.2641-5	3.1095-4	2.0460-3	8.5693-3	2.5605-2	5.7994-2	<b>1.0327-1</b>	<b>1.4802-1</b>	<b>1.7347-1</b>	<b>1.6790-1</b>	<b>1.3507-1</b>	9.0595-2
1	1.8507-4	2.0886-3	1.0933-2	3.4872-2	7.4613-2	<b>1.1026-1</b>	1.0966-1	6.4327-2	1.1898-2	4.5902-3	5.3129-2	<b>1.1554-1</b>
2	7.9208-4	7.2777-3	2.9747-2	6.9589-2	<b>9.8353-2</b>	7.7835-2	2.2280-2	1.4296-3	4.3261-2	<b>8.2242-2</b>	<b>5.6926-2</b>	7.1534-3
3	2.3640-3	1.7488-2	5.4452-2	<b>8.8170-2</b>	7.0117-2	1.4830-2	5.9847-2	<b>5.2637-2</b>	<b>6.0405-2</b>	1.2960-2	7.9981-3	<b>5.9707-2</b>
4	5.5296-3	3.2490-2	7.4499-2	2.1921-2	3.2797-3	4.7031-2	4.8606-2	3.9214-3	3.9214-3	2.0276-2	<b>5.8742-2</b>	2.6351-2
5	1.0802-2	4.9588-2	<b>7.9752-2</b>	4.1836-2	3.7157-5	<b>3.3852-2</b>	<b>4.8235-2</b>	4.9013-3	1.9158-2	<b>5.0219-2</b>	1.2252-2	1.0677-2
6	1.8342-2	6.4437-2	6.7470-2	1.0719-2	1.3818-2	<b>4.9225-2</b>	1.3360-2	9.9095-3	<b>4.5081-2</b>	1.2101-2	1.0996-2	<b>4.6567-2</b>
7	2.7819-2	<b>7.2876-2</b>	4.3780-2	2.3794-5	3.7263-2	3.0752-2	6.8564-4	<b>3.7234-2</b>	2.0120-2	4.8586-3	<b>4.0709-2</b>	1.1249-2
8	3.8444-2	7.2602-2	1.9422-2	9.9449-3	<b>4.3958-2</b>	5.0880-3	1.9595-2	3.2580-2	1.0085-6	<b>3.2189-2</b>	1.7899-2	6.3211-3
9	4.9137-2	6.3933-2	3.6587-3	2.7687-2	3.0196-2	1.2400-3	<b>3.5473-2</b>	7.9236-3	1.6005-2	2.8670-2	2.8389-4	<b>3.2754-2</b>
10	5.8772-2	4.9435-2	2.9977-4	<b>3.9271-2</b>	1.0517-2	1.5594-2	2.7802-2	8.2478-4	<b>3.1758-2</b>	4.6967-3	1.9531-2	2.1129-2
11	6.6403-2	3.2817-2	7.3542-3	3.8256-2	2.8930-4	2.9905-2	8.9732-3	1.5262-2	2.1772-2	3.0509-3	<b>2.9308-2</b>	5.1501-4
12	7.1413-2	1.7689-2	1.9359-2	2.7069-2	4.0595-3	<b>3.0554-2</b>	5.3481-6	<b>2.7836-2</b>	3.8248-3	2.0008-2	1.2639-2	9.9564-3
13	<b>7.3571-2</b>	6.6513-3	3.0450-2	1.2957-2	1.5812-2	1.8994-2	6.7309-3	2.3689-2	1.4319-3	<b>2.5947-2</b>	5.4662-5	<b>2.4982-2</b>
14	7.2996-2	9.0715-4	<b>3.6607-2</b>	2.8272-3	2.6140-2	5.7878-3	1.9242-2	9.6232-3	1.3388-2	1.4008-2	8.1734-3	1.8479-2
15	7.0071-2	3.4677-4	3.6490-2	7.3785-5	<b>2.8933-2</b>	2.9455-2	<b>2.5371-2</b>	4.6136-4	<b>2.2955-2</b>	1.5109-3	<b>2.0787-2</b>	3.2791-3
16	6.5333-2	3.9283-3	3.1067-2	4.1473-3	2.3758-2	3.6267-2	2.1099-2	2.8819-3	2.0191-2	2.0937-3	2.0154-2	1.3501-3
17	5.9370-2	1.0150-2	2.2610-2	1.1976-2	1.4337-2	1.2312-2	1.0996-2	1.2232-2	9.4610-3	1.2049-2	8.8015-3	1.1875-2
18	5.2740-2	1.7496-2	1.3658-2	1.9905-2	5.4717-3	2.0021-2	2.4494-3	1.9680-2	1.1169-3	<b>1.9368-2</b>	4.7738-4	<b>1.9226-2</b>
19	4.5918-2	<b>2.4574-2</b>	6.2527-3	<b>2.5168-2</b>	5.6450-4	<b>2.2715-2</b>	8.8207-5	<b>1.9966-2</b>	1.0485-3	1.7461-2	2.5012-3	1.5252-2

$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	5.0680-2	2.3597-2	9.1027-3	2.8878-3	7.4549-4	1.5431-4	2.5096-5	3.1173-6	2.8377-7	1.7756-8	6.8421-10	1.3104-11
1	<b>1.4289-1</b>	<b>1.2329-1</b>	7.9833-2	4.0015-2	1.5714-2	4.8388-3	1.1594-3	2.1269-4	2.9090-5	2.8443-6	1.8574-7	7.1708-9
2	1.2322-2	7.5864-2	<b>1.3042-1</b>	<b>1.2986-1</b>	8.8602-2	4.4083-2	1.6385-2	4.5704-3	9.4761-4	1.4263-5	1.4943-5	1.0123-6
3	<b>6.8819-2</b>	1.8319-2	4.7608-3	6.5497-2	<b>1.2784-1</b>	<b>1.2901-1</b>	8.4249-2	3.8424-2	1.2571-2	2.9539-3	4.8919-4	5.4748-5
4	1.6224-3	<b>4.9422-2</b>	<b>6.8023-2</b>	1.7696-2	6.9462-3	7.5792-2	<b>1.3454-1</b>	<b>1.2204-1</b>	6.9882-2	2.7081-2	7.2370-3	1.3185-3
5	<b>5.3768-2</b>	2.6914-2	2.0392-3	<b>5.2566-2</b>	<b>6.2060-2</b>	8.4628-3	1.9486-2	1.0119-1	<b>1.4083-1</b>	1.0463-1	4.8636-2	1.4846-2
6	1.2174-2	1.1883-2	<b>5.2743-2</b>	1.8414-2	<b>6.3074-2</b>	<b>4.6872-2</b>	1.4697-4	5.0250-2	<b>1.3195-1</b>	<b>1.3361-1</b>	7.5724-2	1.5735-2
7	1.2526-2	<b>4.3854-2</b>	5.9108-3	2.1177-2	<b>5.0030-2</b>	5.5485-3	2.5526-2	<b>6.9044-2</b>	2.0771-2	1.0895-2	9.9568-2	<b>1.4868-1</b>
8	<b>3.8668-2</b>	5.1603-3	2.1119-2	<b>3.7423-2</b>	1.3630-4	<b>3.7517-2</b>	<b>6.4002-2</b>	<b>5.2480-4</b>	<b>5.3480-2</b>	<b>5.3560-2</b>	3.8131-4	5.7535-2
9	1.0370-2	1.3545-2	<b>3.3789-2</b>	7.1077-5	<b>3.4275-2</b>	2.1768-2	6.4394-3	<b>4.8990-2</b>	1.1683-2	2.0438-2	<b>6.9370-2</b>	1.6505-2
10	3.6263-3	<b>3.2974-2</b>	1.8543-3	<b>6.0339-2</b>	2.0389-2	6.1236-3	<b>4.0558-2</b>	3.1124-3	<b>3.0510-2</b>	<b>3.8206-2</b>	8.0584-4	<b>5.8834-2</b>
11	<b>2.6162-2</b>	9.7428-3	1.3830-2	2.5200-2	1.7025-3	<b>3.4698-2</b>	3.3557-3	<b>2.6629-2</b>	2.5301-2	5.4405-3	<b>4.9403-2</b>	6.8086-3
12	2.2465-2	1.9396-3	<b>2.8637-2</b>	4.8447-4	<b>2.7188-2</b>	8.5052-3	1.7183-2	2.4509-2	3.9466-3	<b>3.9391-2</b>	1.6645-3	<b>3.6562-2</b>
13	2.8160-3	2.0608-2	9.3923-3	1.3518-2	1.8548-2	5.6115-3	<b>2.7767-2</b>	3.4153-4	<b>3.3007-2</b>	2.7896-3	<b>2.9233-2</b>	1.8219-2
14	3.8203-3	<b>2.2451-2</b>	8.6198-4	<b>2.5221-2</b>	5.3306-5	<b>2.5973-2</b>	2.3389-3	<b>2.3817-2</b>	8.7590-3	1.8041-2	2.0035-2	8.9963-3
15	1.8480-2	5.806-3	1.5834-2	9.3064-3	1.2750-2	1.3723-2	9.2113-3	1.9137-2	5.3677-3	<b>2.5428-2</b>	1.7733-3	<b>3.1991-2</b>
16	<b>2.0625-2</b>	7.1007-4	<b>2.1427-2</b>	2.3282-4	<b>2.2458-2</b>	4.5613-6	<b>2.3633-2</b>	1.8138-4	<b>4.2827-2</b>	1.0716-3	<b>2.5782-2</b>	3.3045-3
17	8.6593-3	1.1749-2	8.8898-3	1.1678-2	9.4554-3	1.1646-2	1.0397-2	1.1612-2	1.1841-2	1.1487-2	1.4040-2	1.1104-2
18	1.6500-4	<b>1.9296-2</b>	2.8616-5	<b>1.9595-2</b>	5.5027-6	<b>2.0148-2</b>	5.1225-5	<b>2.1003-2</b>	1.5523-4	<b>2.2551-2</b>	2.8413-4	<b>2.4061-2</b>
19	4.1831-3	1.3281-2	6.0357-3	1.1478-2	8.0662-3	9.7961-3	<b>1.0301-2</b>	8.2149-3	<b>1.2773-2</b>	6.7481-3	<b>1.5520-2</b>	5.4418-3

TABLE 4. *Franck-Condon factors to high vibrational quantum numbers for the NO  $\gamma$  (A<sup>2</sup>Z<sup>+</sup>—X<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	1.6725-1	<b>2.6456-1</b>	<b>2.3741-1</b>	<b>1.5978-1</b>	9.0065-2	4.5066-2	2.0735-2	8.9783-3	3.7184-3	1.4904-3	5.8326-4	2.2439-4
1	<b>3.3431-1</b>	1.0242-1	1.1580-3	7.4263-2	<b>1.3583-1</b>	<b>1.3330-1</b>	<b>9.7259-2</b>	5.9428-2	3.2279-2	1.6143-2	7.6040-3	3.4276-3
2	2.9262-1	1.7957-2	<b>1.5684-1</b>	7.1223-2	1.7613-4	3.7296-2	9.0778-2	<b>1.0578-1</b>	<b>8.8529-2</b>	6.0987-2	3.0946-2	2.0450-2
3	1.4727-1	2.0259-1	4.2298-2	4.3396-2	<b>1.1315-1</b>	4.6214-2	9.8246-5	2.6552-2	6.8918-2	<b>8.6432-2</b>	<b>7.9806-2</b>	5.8111-2
4	4.7062-2	<b>2.4039-1</b>	4.6886-2	<b>1.2242-1</b>	6.9213-4	<b>6.1636-2</b>	<b>8.5428-2</b>	2.8433-2	3.0659-5	2.2765-2	5.6663-2	<b>7.2814-2</b>
5	9.9525-3	1.2656-1	<b>2.1521-1</b>	5.6888-4	<b>1.1140-1</b>	4.1408-2	8.1102-3	<b>6.8293-2</b>	<b>6.3115-2</b>	1.6371-2	5.1617-4	2.1236-2
6	1.4083-3	3.7778-2	1.9572-1	1.2393-1	4.2608-2	4.8568-2	<b>8.3044-2</b>	4.8751-3	2.5923-2	<b>6.5414-2</b>	<b>4.5018-2</b>	8.6661-3
7	1.3177-4	6.9230-3	8.2277-2	<b>2.2299-1</b>	3.9266-2	<b>2.9249-1</b>	1.3818-3	<b>8.0926-2</b>	3.5837-2	1.1101-3	3.9436-2	<b>5.7040-2</b>
8	7.8608-6	7.9343-4	1.9317-2	1.3398-1	<b>2.0249-1</b>	1.3818-3	<b>1.1050-1</b>	5.9887-3	<b>6.6390-2</b>	<b>6.2561-2</b>	7.5553-3	1.0899-2
9	2.7802-7	5.5665-5	2.6807-3	4.0138-2	1.8008-1	1.4909-1	1.1266-2	<b>8.5860-2</b>	3.6115-2	1.2055-2	<b>6.3411-2</b>	3.1088-2
10	5.0323-9	2.2372-6	2.1887-4	6.6919-3	6.8965-2	<b>2.0966-1</b>	8.6078-2	4.6944-2	4.4405-2	<b>6.5703-2</b>	2.6556-5	<b>4.2137-2</b>
11	3.1794-11	4.4416-8	9.9004-6	6.3044-4	1.3747-2	1.0341-1	<b>2.1685-1</b>	3.4125-2	<b>8.2605-2</b>	1.1286-2	<b>7.5315-2</b>	1.1680-2
12	1.0538-14	2.9465-10	2.1360-7	3.1855-5	1.4852-3	2.4584-2	1.3968-1	<b>2.0170-1</b>	5.1603-3	<b>1.0092-1</b>	5.2344-6	<b>6.2603-2</b>
13	5.9817-16	4.3432-14	1.4460-9	7.4066-7	8.3254-5	3.0310-3	3.9587-2	1.7345-1	1.6912-1	1.2674-3	<b>9.6855-2</b>	1.0133-2
14	7.5344-16	1.9828-15	3.9044-14	5.0256-9	2.0707-6	1.8743-4	5.5490-3	5.8691-2	<b>2.0072-1</b>	1.2680-1	1.6959-2	<b>7.5373-2</b>
15	3.5559-16	1.1501-15	4.3289-14	4.0394-14	1.3928-8	4.9547-6	3.7671-4	9.3270-3	8.1363-2	<b>2.1848-1</b>	8.3053-2	4.2871-2

$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	8.5321-5	3.2200-5	1.2103-5	4.5436-6	1.7076-6	6.4374-7	2.4383-7	9.2921-8	3.5672-8	1.3808-8	5.3939-9	2.1276-9
1	1.4955-3	6.3699-4	2.6664-4	1.1026-4	4.5231-5	1.8468-5	7.5271-6	3.0692-6	1.2545-6	5.1486-7	2.1247-7	8.8272-8
2	1.0599-2	5.2320-3	2.4900-3	1.1530-3	5.2316-4	2.3391-4	1.0351-4	4.5502-5	1.9930-5	8.7193-6	3.8184-6	1.6768-6
3	3.8016-2	2.2703-2	1.2681-2	6.7373-3	3.4464-3	1.7131-3	8.3333-4	3.9895-4	1.8882-4	8.8677-5	4.1452-5	1.9336-5
4	<b>6.8746-2</b>	5.3940-2	3.7374-2	2.3698-2	1.4072-2	7.9528-3	4.3281-3	2.2886-3	1.1839-3	6.0252-4	3.0300-4	1.5113-4
5	4.8783-2	<b>6.2751-2</b>	<b>6.0844-2</b>	4.9624-2	3.5983-2	2.3973-2	1.4995-2	8.9412-3	5.1390-3	2.8715-3	1.5702-3	8.4479-4
6	1.4526-3	2.0410-2	4.3056-2	<b>5.4195-2</b>	<b>5.4193-2</b>	4.5567-2	3.4317-2	2.3857-2	1.5620-2	9.7696-3	5.8983-3	3.4653-3
7	3.1024-2	4.1023-3	2.5505-3	1.9679-2	3.8461-2	<b>4.8531-2</b>	<b>4.8541-2</b>	4.1881-2	3.2604-2	2.3544-2	1.6064-2	2.3138-2
8	<b>4.5363-2</b>	<b>4.6723-2</b>	2.0772-2	1.6488-3	3.5524-3	1.8797-2	3.4499-2	<b>4.3134-2</b>	<b>4.3666-2</b>	<b>3.8564-2</b>	3.0944-2	<b>3.9987-2</b>
9	1.4810-6	2.2000-2	<b>4.5125-2</b>	<b>3.6747-2</b>	1.1627-2	5.0016-4	4.2935-3	1.7682-2	3.0914-2	3.8431-2	<b>3.9387-2</b>	<b>3.5569-2</b>
10	<b>4.9878-2</b>	9.3400-3	3.9025-3	2.9486-2	<b>4.1250-2</b>	2.8229-2	8.8623-3	7.7910-5	4.6979-3	1.6330-2	2.7569-2	3.4225-2
11	1.6139-2	<b>5.1337-2</b>	2.7800-2	7.2225-4	1.1148-2	<b>3.2700-2</b>	<b>3.5878-2</b>	2.1503-2	5.8073-3	2.8993-7	4.7560-3	1.4768-2
12	3.4143-2	1.2195-3	<b>3.6912-2</b>	<b>4.1425-2</b>	1.0967-2	7.6408-4	1.7442-2	<b>3.2675-2</b>	<b>3.0367-2</b>	1.6473-2	3.9313-3	3.8995-5
13	<b>3.7595-2</b>	<b>5.2056-2</b>	3.0281-3	1.7060-2	<b>4.2315-2</b>	2.5738-2	2.3872-3	4.4728-3	2.1384-2	<b>3.0738-2</b>	<b>2.5451-2</b>	1.2866-2
14	3.2091-2	1.3825-2	<b>5.6247-2</b>	1.6982-2	2.9801-3	<b>3.1414-2</b>	<b>3.5468-2</b>	1.2730-2	1.3328-5	8.6620-3	2.3068-2	<b>2.7953-2</b>
15	<b>4.6484-2</b>	<b>5.3923-2</b>	1.1027-3	<b>4.6382-2</b>	3.3404-2	5.5857-4	1.5809-2	<b>3.5165-2</b>	<b>2.4487-2</b>	4.7740-3	9.1640-4	1.1894-2

TABLE 5. *Franck-Condon factors to high vibrational quantum numbers for the NO  $\delta$  (C<sup>2</sup>II-X<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	1.5303-1	<b>2.5430-1</b>	<b>2.3802-1</b>	<b>1.6619-1</b>	9.6817-2	4.9932-2	2.3636-2	1.0519-2	4.4751-3	1.8427-3	7.4117-4	2.9329-4
1	<b>3.1826-1</b>	1.1664-1	3.4184-8	6.0911-2	<b>1.2759-1</b>	<b>1.3451-1</b>	<b>1.0312-1</b>	6.5614-2	3.6935-2	1.9091-2	9.2807-3	4.3144-3
2	2.9469-1	7.9811-3	<b>1.4637-1</b>	<b>8.5132-2</b>	2.7400-3	2.5826-2	8.0610-2	<b>1.0384-1</b>	<b>9.2717-2</b>	6.7154-2	4.2452-2	2.4415-2
3	1.6035-1	1.7343-1	6.0846-2	2.6051-2	<b>1.0916-1</b>	<b>6.0224-2</b>	2.7988-3	1.6040-2	5.8190-2	<b>8.2301-2</b>	<b>8.0396-2</b>	6.3852-2
4	5.7021-2	<b>2.3879-1</b>	2.3254-2	<b>1.2922-1</b>	7.2589-3	4.3165-2	<b>8.7758-2</b>	4.2110-2	1.6653-3	1.2539-2	4.5861-2	<b>6.8235-2</b>
$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	1.1482-4	4.4676-5	1.7338-5	6.7318-6	2.6214-6	1.0259-6	4.0423-7	1.6060-7	6.4411-8	2.6109-8	1.0705-8	4.4435-9
1	1.9412-3	8.5299-4	3.6861-4	1.5751-4	6.6851-5	2.8281-5	1.1960-5	5.0690-6	2.1574-6	9.2372-7	3.9846-7	1.7339-7
2	1.3117-2	6.7023-3	3.2999-3	1.5807-3	7.4226-4	3.4367-4	1.5764-4	7.1906-5	3.2722-5	1.4895-5	6.7968-6	3.1150-6
3	4.3869-2	2.7359-2	1.5905-2	8.7778-3	4.6592-3	2.4021-3	1.2119-3	6.0200-4	2.9580-4	1.4435-4	7.0177-5	3.4085-5
4	7.0512-2	5.9148-2	4.3297-2	2.8806-2	1.7873-2	1.0527-2	5.9615-3	3.2773-3	1.7621-3	9.3202-4	4.8729-4	2.5281-4

TABLE 6. *Franck-Condon factors to high vibrational quantum numbers for the NO  $\epsilon$  (D<sup>2</sup> $\Sigma^+$ -X<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	1.6588-1	<b>2.5830-1</b>	<b>2.3329-1</b>	<b>1.6030-1</b>	9.3089-2	4.8237-2	2.3038-2	1.0357-2	4.4465-3	1.8421-3	7.4210-4	2.9239-4
1	<b>3.5011-1</b>	1.0080-1	9.9080-4	6.8939-2	<b>1.2782-1</b>	<b>1.2813-1</b>	<b>9.6030-2</b>	6.0461-2	3.3872-2	1.7458-2	8.4579-3	3.9080-3
2	3.0414-1	2.7624-2	<b>1.5930-1</b>	6.5280-2	6.1723-5	3.5537-2	8.5003-2	<b>9.9710-2</b>	<b>8.4761-2</b>	5.9552-2	3.6842-2	2.0812-2
3	1.3914-1	2.4466-1	2.6133-2	5.7407-2	<b>1.0916-1</b>	3.7944-2	1.7524-5	2.7373-2	6.5869-2	<b>8.1111-2</b>	<b>7.3182-2</b>	5.4780-2
4	3.5527-2	<b>2.4918-1</b>	9.4737-2	<b>1.0409-1</b>	1.2430-3	<b>7.3266-2</b>	<b>7.5852-2</b>	1.9318-2	8.0186-4	2.5773-2	5.5977-2	<b>6.8586-2</b>
5	4.9046-3	9.9762-2	<b>2.7168-1</b>	1.1081-2	<b>1.2446-1</b>	1.7093-2	2.2750-2	<b>7.2794-2</b>	<b>4.9230-2</b>	<b>7.8166-3</b>	2.8982-3	2.6240-2
6	3.1618-4	1.8287-2	1.7000-1	<b>2.2885-1</b>	4.2543-3	<b>9.1441-2</b>	<b>5.4692-2</b>	4.7379-4	4.3883-2	<b>6.1092-2</b>	2.8727-2	1.9091-3
7	5.7018-6	1.3859-3	4.0353-2	2.2847-1	1.6074-4	3.5644-2	4.5282-2	<b>7.6794-2</b>	7.7805-3	1.5239-2	<b>5.1876-2</b>	<b>4.4812-2</b>
8	9.6899-9	2.3825-5	3.4892-3	6.8911-2	<b>2.6769-1</b>	9.6204-2	<b>7.0993-2</b>	1.2617-2	<b>7.5117-2</b>	2.7981-2	1.1079-3	3.2171-2
9	5.6809-9	1.8790-7	5.2947-5	6.6130-3	1.0096-1	<b>2.8811-1</b>	4.8315-2	<b>9.3543-2</b>	3.2044-4	<b>5.7738-2</b>	<b>4.5765-2</b>	2.2409-3
10	7.3032-12	3.8313-8	1.3231-6	7.9711-5	1.0461-2	1.3381-1	<b>2.9422-1</b>	1.8977-2	<b>1.0018-1</b>	3.8388-3	3.5876-2	<b>5.3909-2</b>
11	7.9047-12	3.3321-10	1.2892-7	5.5882-6	8.4722-5	1.4540-2	1.6551-1	<b>2.9157-1</b>	4.6190-3	<b>9.4486-2</b>	1.5442-2	1.7394-2
$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	1.1317-4	4.3176-5	1.6279-5	6.0774-6	2.2498-6	8.2658-7	3.0156-7	1.0925-7	3.9284-8	1.4005-8	4.9415-9	1.7208-9
1	1.7402-3	7.5254-4	3.1788-4	1.3174-4	5.3748-5	2.1642-5	8.6174-6	3.3975-6	1.3275-6	5.1422-7	1.9744-7	7.5088-8
2	1.0987-2	5.5063-3	2.6493-3	1.2340-3	5.5994-4	2.4870-4	1.0852-4	4.6661-5	1.9810-5	8.3178-6	3.4577-6	1.4238-6
3	3.6149-2	2.1781-2	1.2258-2	6.5436-3	3.3506-3	1.6593-3	7.9981-4	3.7705-4	1.7450-4	7.9524-5	3.5765-5	1.5901-5
4	<b>6.3389-2</b>	4.9235-2	3.3939-2	2.1443-2	1.2682-2	7.1239-3	3.8415-3	2.0043-3	1.0181-3	5.0583-4	2.4675-4	1.1854-4
5	4.9966-2	<b>5.9522-2</b>	<b>5.5314-2</b>	4.3907-2	3.1215-2	2.0455-2	1.2593-2	7.3819-3	4.1611-3	2.2725-3	1.2093-3	6.2997-4
6	5.9169-3	2.7203-2	4.5736-2	<b>5.2484-2</b>	<b>4.8597-2</b>	3.9086-2	2.8435-2	1.9189-2	1.2219-2	7.4313-3	4.3562-3	2.4783-3
7	1.4425-2	2.8285-5	5.6900-3	2.7989-2	4.2235-2	<b>4.6703-2</b>	<b>4.2927-2</b>	3.4823-2	2.5802-2	1.7850-2	1.1705-2	7.3565-3
8	<b>4.8059-2</b>	2.9026-2	5.2940-3	7.0713-4	1.2367-2	2.8320-2	3.9070-2	<b>4.1769-2</b>	<b>3.8083-2</b>	3.1091-2	2.3399-2	1.6546-2
9	1.3544-2	<b>3.9989-2</b>	<b>3.7873-2</b>	1.6437-2	1.3354-3	7.7327-3	1.4937-2	2.8119-2	3.6069-2	<b>3.7458-2</b>	<b>3.3906-2</b>	2.7839-2
10	1.2408-2	2.5127-3	2.6212-3	<b>3.8493-2</b>	2.6214-2	7.8228-3	1.4750-5	5.2175-3	1.6798-2	2.7422-2	3.3180-2	<b>3.3642-2</b>
11	<b>5.2147-2</b>	2.4534-2	1.3430-4	1.3426-2	<b>3.2452-2</b>	<b>3.1465-2</b>	1.6044-2	2.8045-3	5.1857-4	7.5892-3	1.7928-2	2.6317-2

TABLE 7. *Franck-Condon factors to high vibrational quantum numbers for the NO  $\beta'$  (B'<sup>2</sup> $\Delta$ -X<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	1.8358-2	8.3318-2	<b>1.7687-1</b>	<b>2.3362-1</b>	<b>2.1542-1</b>	<b>1.4749-1</b>	7.7849-2	3.2466-2	1.0877-2	2.9605-3	6.5948-4	1.2076-4
1	5.8594-2	<b>1.5426-1</b>	1.4162-1	3.4431-2	6.8166-3	9.3789-2	<b>1.7119-1</b>	<b>1.6350-1</b>	1.0405-1	4.8403-2	1.7244-2	4.8310-3
2	1.8234-2	1.3858-1	2.4259-2	2.4264-2	<b>1.0688-1</b>	6.5626-2	3.5856-4	5.3227-2	<b>1.4300-1</b>	<b>1.5775-1</b>	1.0719-1	5.1162-2
3	1.3331-1	7.1848-2	5.6975-3	<b>8.8161-2</b>	3.8636-2	8.5167-3	<b>8.6451-2</b>	<b>6.5503-2</b>	1.0381-3	4.7414-2	<b>1.3547-1</b>	<b>1.5018-1</b>
4	<b>1.4163-1</b>	1.6810-2	5.0973-2	5.7444-2	2.7502-3	<b>7.3045-2</b>	3.2065-2	9.8989-3	<b>8.2331-2</b>	<b>5.4604-2</b>	1.4135-5	5.6873-2
5	1.3163-1	2.4605-5	<b>7.5678-2</b>	7.0741-3	4.7790-2	3.9753-2	7.4184-3	<b>6.9260-2</b>	1.8513-2	1.9357-2	<b>8.2901-2</b>	3.7695-2
6	1.1117-1	<b>1.3118-2</b>	5.9638-2	5.5592-3	<b>5.9402-2</b>	1.8304-4	<b>5.4105-2</b>	2.0365-2	<b>1.9830-2</b>	<b>6.3426-2</b>	5.1730-3	3.6551-2
$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	1.8210-5	2.2607-6	2.3052-7	1.9206-8	1.2959-9	7.0744-11	3.1971-12	9.1352-14	6.7896-16	1.4617-15	1.0247-17	7.7555-16
1	1.0812-3	1.9507-4	2.8509-5	3.3782-6	3.2389-7	2.5016-8	1.5473-9	7.5319-11	2.7691-12	9.4006-14	2.9641-15	4.3000-16
2	1.8234-2	5.0168-3	1.0863-3	1.8714-4	2.5790-5	2.8460-6	2.5088-7	1.7569-8	9.6709-10	4.0835-11	1.3275-12	3.9485-14
3	1.0035-1	4.6455-2	1.5884-2	4.1519-3	8.4605-4	1.3586-4	1.7272-5	1.7388-6	1.3806-7	8.5018-9	4.0909-10	1.5428-11
4	<b>1.4128-1</b>	<b>1.4128-1</b>	8.8042-2	3.8075-2	1.2130-2	2.9401-3	5.5198-4	8.1016-5	9.3256-6	8.4029-7	5.8892-8	3.1800-9
5	2.4457-3	7.5874-2	<b>1.4415-1</b>	<b>1.2892-1</b>	7.2534-2	2.8579-2	8.3082-3	1.8329-3	3.1160-4	4.1104-5	4.2111-6	3.3356-7
6	<b>7.9081-2</b>	1.8448-2	1.3839-2	1.0006-1	<b>1.4617-1</b>	1.1210-1	5.5842-2	1.9706-2	5.1460-3	1.0180-3	1.5437-4	1.8019-5



TABLE 8. *Franck-Condon factors to high vibrational quantum numbers for the NO  $\gamma^1(E^2\Sigma^+ - X^2II)$  band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	1.8292-1	<b>2.7657-1</b>	<b>2.3718-1</b>	<b>1.5256-1</b>	8.2230-2	3.9369-2	1.7346-2	7.1987-3	2.8604-3	1.1012-3	4.1436-4	1.5345-4
1	<b>3.4419-1</b>	8.8265-2	4.8132-3	9.0257-2	<b>1.4532-1</b>	<b>1.3244-1</b>	9.1120-2	5.2865-2	2.7374-2	1.3087-2	5.9058-3	2.5550-3
2	2.8488-1	2.2688-2	<b>1.6337-1</b>	5.8596-2	6.1843-4	5.0870-2	<b>1.0194-1</b>	<b>1.0809-1</b>	<b>8.4501-2</b>	5.4997-2	3.1674-2	1.6735-2
3	1.3638-1	2.1667-2	3.0458-2	5.8301-2	<b>1.1413-1</b>	3.4941-2	8.4098-4	3.8518-2	7.9760-2	<b>8.9988-2</b>	<b>7.5535-2</b>	5.2958-2
4	4.1780-2	<b>2.3390-1</b>	6.1865-2	<b>1.1475-1</b>	1.8000-4	<b>7.5107-2</b>	<b>8.1670-2</b>	1.8913-2	1.9603-3	3.3699-2	6.6678-2	<b>7.6744-2</b>
5	8.5623-3	1.1620-1	<b>2.2212-1</b>	1.5384-4	<b>1.1958-1</b>	3.0105-2	1.6595-2	<b>7.6998-2</b>	5.6403-2	8.9686-3	3.6710-3	3.1358-2
$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	5.6232-5	2.0476-5	7.4344-6	2.6992-6	9.8222-7	3.5895-7	1.3195-7	4.8862-8	1.8247-8	6.8785-9	2.6195-9	1.0084-9
1	1.0717-3	4.3949-4	1.7738-4	7.0817-5	2.8084-5	1.1100-5	4.3843-6	1.7347-6	6.8886-7	2.7500-7	1.1053-7	4.4774-8
2	8.3041-3	3.9337-3	1.8002-3	8.0297-4	3.5152-4	1.5186-4	6.5028-5	2.7698-5	1.1770-5	5.0020-6	2.1304-6	9.1099-7
3	3.2889-2	1.8737-2	1.0020-2	5.1101-3	2.5150-3	1.2051-3	5.6609-4	2.6212-4	1.2016-4	5.4738-5	2.4852-5	1.1273-5
4	<b>6.7155-2</b>	4.9581-2	3.2599-2	1.9720-2	1.1215-2	6.0882-3	3.1904-3	1.6277-3	8.1396-4	4.0107-4	1.9558-4	9.4721-5
5	5.7873-2	<b>6.6675-2</b>	5.9894-2	4.5962-2	3.1634-2	2.0118-2	1.2061-2	6.9141-3	3.8302-3	2.0672-3	1.0939-3	5.7045-4

 TABLE 9. *Franck-Condon factors to high vibrational quantum numbers for the NO Feast 1 ( $D^2\Sigma^+ - A^2\Sigma^+$ ) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8
0	<b>9.9969-1</b>	1.8711-4	1.2792-4	4.2490-7	1.9841-7	5.0558-8	6.3344-9	6.0985-10	4.3012-11
1	1.8680-4	<b>9.9943-1</b>	2.3871-7	3.8609-4	2.6853-6	7.9047-7	2.4905-7	3.5216-8	3.8579-9
2	1.2809-4	7.3738-7	<b>9.9843-1</b>	6.3266-4	8.1095-4	1.0154-5	1.8354-6	7.1982-7	1.1145-7
3	3.5713-7	3.8558-4	7.2150-4	<b>9.9407-1</b>	3.3205-3	1.4801-3	2.9837-5	3.1627-6	1.5993-6
4	5.8411-7	1.1705-7	7.2576-4	3.8448-3	<b>9.8354-1</b>	9.3034-3	2.5250-3	7.5208-5	4.3234-6
5	5.0012-8	2.6448-6	6.7206-7	1.0513-3	1.1049-2	<b>9.6385-1</b>	1.9746-2	4.1490-3	1.7088-4
6	2.7548-9	3.5170-7	6.7176-6	9.1700-6	1.2300-3	2.4096-2	<b>9.3205-1</b>	3.5616-2	6.6496-3
7	2.2567-10	2.5801-8	1.3823-6	1.2174-5	3.9537-5	1.1380-3	4.4657-2	<b>8.8552-1</b>	5.7506-2
8	3.7741-11	2.2890-9	1.3468-7	3.9507-6	1.6793-5	1.0863-4	7.3893-4	7.4031-2	<b>8.2227-1</b>
9	8.7194-12	3.7557-10	1.3324-8	5.1088-7	9.0455-6	1.7403-5	2.2596-4	2.0102-4	1.1279-1
10	2.1009-12	9.1238-11	2.1272-9	5.8012-8	1.5584-6	1.7336-5	1.2044-5	3.7816-4	4.1487-5
11	5.0514-13	2.3801-11	5.2379-10	9.2181-9	2.0777-7	4.0169-6	2.8339-5	3.2728-6	5.1520-4
$v' \backslash v''$	9	10	11	12	13	14	15		
0	1.6911-12	2.3259-16	3.1030-14	1.3183-14	1.3826-15	1.6314-16	5.8860-16		
2	3.0600-10	1.3939-11	3.8679-14	1.8562-13	1.5501-13	6.4102-14	1.5042-14		
3	1.3713-8	1.2183-9	6.2007-11	1.8049-13	8.9484-13	7.0660-13	3.0022-13		
4	2.6348-7	3.5901-8	3.5164-9	2.0186-10	8.4664-13	3.1340-12	2.5370-12		
5	3.0336-6	5.1616-7	7.7344-8	8.2311-9	5.2672-10	3.4074-12	8.4579-12		
6	4.6428-6	5.2018-6	8.8229-7	1.4520-7	1.6592-8	1.1609-9	1.0351-11		
7	3.6005-4	3.5015-6	8.3708-6	1.3538-6	2.4566-7	2.9855-8	2.2503-9		
8	1.0440-2	7.1600-4	1.1120-6	1.3002-5	1.8932-6	3.8328-7	4.9008-8		
9	8.5431-2	1.6061-2	1.3587-3	2.7157-7	1.9942-5	2.4248-6	5.6189-7		
10	<b>7.4152-1</b>	1.1859-1	2.4178-2	2.4779-3	9.8849-6	3.0794-5	2.8234-6		
11	1.6033-1	<b>6.4412-1</b>	1.5518-1	3.5529-2	4.3617-3	5.1516-5	4.8609-5		
12	1.2692-3	2.1446-1	5.3305-1	1.9223-1	5.0831-2	7.4293-3	1.7976-4		

 TABLE 10. *Franck-Condon factors to high vibrational quantum numbers for the NO Feast 2 ( $E^2\Sigma^+ - A^2\Sigma^+$ ) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8
0	<b>9.9870-1</b>	1.2883-3	1.0997-5	4.9375-9	1.0915-9	1.0213-10	5.6952-12	3.3202-13	2.4765-14
1	1.2730-3	<b>9.9633-1</b>	2.3741-3	3.4489-5	3.2079-8	4.7978-9	6.0333-10	4.0994-11	2.8670-12
2	2.5361-5	2.3180-3	<b>9.9433-1</b>	3.2624-3	7.1876-5	1.1942-7	1.2403-8	2.0753-9	1.6988-10
3	3.2103-7	7.3484-5	3.1471-3	<b>9.9271-1</b>	3.9593-3	1.2441-4	3.3486-7	2.4348-8	5.3691-9
4	2.7010-9	1.2658-6	1.4188-4	3.7731-3	<b>9.9144-1</b>	4.4718-3	1.9316-4	7.8683-7	3.9737-8
5	9.3350-13	1.4230-8	3.1152-6	2.2815-4	4.2094-3	<b>9.9050-1</b>	4.8079-3	2.7895-4	1.6346-6

$v' \backslash v''$	9	10	11	12	13	14	15
0	3.2792-15	1.4501-15	4.7722-16	7.8604-17	1.0406-15	6.2341-16	4.5463-19
1	2.8291-13	3.0768-14	6.4091-16	2.0026-16	1.6107-17	2.9577-18	6.4610-17
2	1.2876-11	1.1715-12	1.5147-13	1.4358-14	2.0644-16	1.2891-15	2.6996-18
3	5.1906-10	4.4829-11	4.1309-12	4.6474-13	6.8501-14	5.5006-15	4.0016-16
4	1.1648-8	1.3082-9	1.2731-10	1.3003-11	1.4734-12	2.0122-13	2.7711-14
5	5.6031-8	2.2302-8	2.8997-9	3.1344-10	3.5110-11	4.2122-12	5.4726-13

TABLE 11. *Franck-Condon factors to high vibrational quantum numbers for the NO Ogawa 1 (B'<sup>2</sup>Δ—B<sup>2</sup>II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10
0	2.2557-1	<b>2.8877-1</b>	<b>2.2351-1</b>	<b>1.3509-1</b>	7.0194-2	3.2915-2	1.4329-2	5.8961-3	2.3208-3	8.8114-4	3.2453-4
1	<b>4.0580-1</b>	4.6505-2	2.3550-2	1.1453-1	<b>1.4223-1</b>	<b>1.1537-1</b>	7.3699-2	4.0680-2	2.0291-2	9.3929-3	4.1043-3
2	2.7386-1	1.1578-1	<b>1.5641-1</b>	1.7228-2	1.6543-2	7.7701-2	<b>1.0553-1</b>	<b>9.3033-2</b>	6.4867-2	3.8907-2	2.0992-2
3	8.3679-2	<b>3.3228-1</b>	3.4276-3	<b>1.2714-1</b>	<b>7.4062-2</b>	2.3923-3	2.1451-2	6.6632-2	<b>8.5455-2</b>	<b>7.5983-2</b>	5.4691-2
4	1.0751-2	1.8393-1	<b>2.6978-1</b>	1.7606-2	5.9222-2	<b>9.5322-2</b>	2.7899-2	5.3014-4	2.8988-2	6.2000-2	<b>7.2264-2</b>
5	3.5658-4	3.1720-2	2.6413-1	1.8477-1	5.8488-2	1.4888-2	<b>8.1219-2</b>	5.2826-2	5.4958-3	6.7032-3	3.6077-2
6	1.2371-6	1.0260-3	5.7520-2	<b>3.1892-1</b>	<b>1.1736-1</b>	8.5432-2	3.5003-4	<b>5.4379-2</b>	<b>6.3103-2</b>	2.0003-2	1.9756-5

$v' \backslash v''$	11	12	13	14	15	16	17	18	19
0	1.1640-4	4.0756-5	1.3947-5	4.6642-6	1.5223-6	4.8350-7	1.4867-7	4.3883-8	1.2264-8
1	1.7124-3	6.8749-4	2.6702-4	1.0068-4	3.6917-5	1.3170-5	4.5652-6	1.5331-6	4.9592-7
2	1.0467-2	4.9076-3	2.1894-3	9.3698-4	3.8680-4	1.5457-4	5.9913-5	2.2531-5	8.2092-6
3	3.4207-2	1.9338-2	1.0124-2	4.9879-3	2.3382-3	1.0510-3	4.5528-4	1.9072-4	7.7389-5
4	<b>6.2697-2</b>	4.5351-2	2.8935-2	1.6827-2	9.1070-3	4.6524-3	2.2655-3	1.0587-3	4.7706-4
5	5.8454-2	<b>6.1900-2</b>	5.1823-2	3.7208-2	2.3934-2	1.4165-2	7.8501-3	4.1227-3	2.0693-3
6	1.6053-2	4.1013-2	<b>5.4306-2</b>	<b>5.2854-2</b>	4.2646-2	3.0243-2	1.9496-2	1.1672-2	6.5842-3

TABLE 12. *Franck-Condon factors to high vibrational quantum numbers for the NO Ogawa 2 (b<sup>4</sup>Σ—a<sup>4</sup>)II band system*

$v' \backslash v''$	0	1	2	3
0	2.5072-1	<b>2.8316-1</b>	<b>2.6542-1</b>	<b>1.2337-1</b>
1	<b>4.1515-1</b>	3.3835-2	2.6702-2	1.0337-1
2	2.5352-1	1.3774-1	<b>1.5569-1</b>	1.9506-2
3	7.0990-2	<b>3.3382-1</b>	3.7309-3	<b>1.2598-1</b>

TABLE 13. *Franck-Condon factors to high vibrational quantum numbers for the NO M (a<sup>4</sup> II—X<sup>2</sup> II) band system*

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	3.6173-5	4.7769-4	2.9981-3	1.1897-2	3.3501-2	7.1222-2	<b>1.1875-1</b>	<b>1.5923-1</b>	<b>1.7473-1</b>	<b>1.5884-1</b>	<b>1.2064-1</b>	7.7007-2
1	2.5281-4	2.7560-3	1.3784-2	4.1550-2	8.2978-2	<b>1.1254-1</b>	9.9641-2	4.7787-2	3.8815-3	1.2840-2	6.9130-2	<b>1.2510-1</b>
2	9.4105-4	8.4217-3	3.3078-2	7.3176-2	<b>9.5485-2</b>	6.6157-2	1.2844-2	5.6499-3	5.3302-2	<b>8.1755-2</b>	4.7163-2	3.0844-3
3	2.4832-3	1.8123-2	5.4838-2	<b>8.4501-2</b>	6.1186-2	9.2341-3	1.0044-2	<b>5.6171-2</b>	<b>5.4831-2</b>	8.3969-3	1.1585-2	<b>6.2308-2</b>

$v' \backslash v''$	12	13	14	15	16	17	18	19	20	21	22	23
0	4.1458-2	1.8860-2	7.2505-3	2.3524-3	6.4232-4	1.4695-4	2.7999-5	4.4077-6	5.6743-7	5.8971-8	4.8694-9	3.1368-10
1	<b>1.4096-1</b>	<b>1.1536-1</b>	7.2979-2	3.6789-2	1.5015-2	5.0007-3	1.3628-3	3.0351-4	5.4999-5	8.0468-6	9.4035-7	8.6529-8
2	1.7871-2	8.1174-2	<b>1.2954-1</b>	<b>1.2693-1</b>	8.8657-2	4.6953-2	1.9434-2	6.3833-3	1.6746-3	3.5112-4	5.8594-5	7.7164-6
3	<b>6.6459-2</b>	1.7411-2	3.9705-3	5.8645-2	<b>1.1957-1</b>	<b>1.2921-1</b>	9.3582-2	4.9531-2	1.9941-2	6.2278-3	1.5213-3	2.9088-4

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(Paper 68A5-300)

## Publications of the National Bureau of Standards\*

### Selected Abstracts

**Thermodynamics of perfect elastic fluids.** B. Bernstein, E. A. Kearsley, and L. J. Zapas, *J. Res. NBS* **68B** (*Math. and Math. Phys.*), No. 3, 103–113 (July–Sept. 1964). 75 cents. A simple nonequilibrium thermodynamics is developed and a particular example is studied. The theory is formulated to describe a viscoelastic fluid, capable of finite deformation, which need not be locally in or near a state of thermodynamic equilibrium. This fluid may support shear stresses only when away from local thermodynamic equilibrium. A notion of time-temperatures superposition is contained in the formulation of the constitutive equations. Conservation of energy is obeyed and the second law of thermodynamics is satisfied as a consequence of simple requirements on the constitutive relations. In an adiabatic isochoric motion the temperature increases when work is done on the material and decreases when the material does work. For given volume and temperature, entropy decreases when the material is deformed from equilibrium. It is shown in what general way viscosity depends upon temperature. For infinitesimal strain, the special form of the stress-strain relations are derived in order to determine how temperature and time-temperature superposition enter in this case.

**Theory of radiation from sources immersed in anisotropic media.** J. R. Wait, *J. Res. NBS* **68B** (*Math. and Math. Phys.*), No. 3, 119–136 (July–Sept. 1964). 75 cents. The electromagnetic fields produced by an electric dipole immersed in an anisotropic medium are considered. Various approaches to the problem are outlined with special reference to a cold plasma. An attempt is made to show the close relationship between previously published work on this subject.

**Response of highly precise balances to thermal gradients.** L. Macurdy, *J. Res. NBS* **68C** (*Eng. and Instr.*), No. 3, 135–140 (July–Sept. 1964). 75 cents.

As small thermal gradients often cause large instabilities in the indications of the more precise balances, an investigation was made of the effects of various types of thermal gradients on several such balances. It was found that the largest instabilities result when the air at the top of the balance case is cooler than that at the bottom, and further that the best performance is obtained when air at the top is warmer, rather than in a state of thermal equilibrium throughout the case. The desired thermal gradients, i.e., top warmer than the bottom, can be achieved through proper insulation of the balance case, with provision being made for some flow of heat in through the lower front of the case and entrapment of warm air at the top of the case. These results apply directly to the equal-arm type of balance; a separate study would be required for balances of different design. However, the general nature of the effects of thermal gradients is applicable to some degree to all types of the more precise balances.

**A new high resolution small-angle x-ray camera.** H. Brumberger and R. Deslattes, *J. Res. NBS* **68C** (*Eng. and Instr.*), No. 3, 173–175 (July–Sept. 1964). 75 cents.

A novel small-angle x-ray camera, utilizing the Borrmann effect in the 220 Laue reflection from germanium to form the incident beam, has been designed and tested. A test pattern of amorphous carbon showed angular resolution of 0.8 milliradian. In principle, an improvement of resolution by an order of magnitude is possible.

**Creep and drying shrinkage and lightweight and normal-weight concretes.** T. W. Reichard, *NBS Mono.* 74 (Mar. 4, 1964), 30 cents.

This is the first edition of a standard on requirements for reinforced masonry. It is a complete code of minimum requirements for reinforced masonry construction, including definitions and requirements for materials, structural design, and allowable stresses. This document, prepared by American Standards Association Sectional Committee A41, under the sponsorship of the National Bureau of Standards, is one of a series of related standards being developed by various committees under the jurisdiction of the Construction Standards Board of the American Standards Association.

**Quantum field theoretic techniques and the electromagnetic properties of a uniformly magnetized electron gas.** L. A. Steinert, *NBS Tech. Note* 207 (Apr. 6, 1964), \$1.50.

Field theoretic operators for the charge,  $\rho$ , and current,  $\vec{j}$ , densities of the electron gas were obtained using the Darwin Hamiltonian in "second quantized" form. Temperature dependent Green's functions were formed from certain averaged combinations of the field creation and annihilation operators. Equations of motion were obtained for

these Green's functions, and  $\rho$  and  $\vec{j}$  were written in terms of the Green's functions.

In order that  $\rho$  and  $\vec{j}$  might be expressed explicitly in terms of the perturbing field, formal functional series expansions

were obtained for  $\rho$  and  $\vec{j}$  in terms of the potentials. Connecting relations obtained from the requirements of gauge invariance and charge conservation were used to show the

general result that  $\rho$  and  $\vec{j}$  reduce to functionals of the electric field alone.

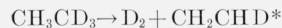
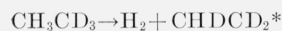
Using the "self-consistent field" approximation, calculations

were performed determining  $\vec{j}$  explicitly to an order linear in the perturbing electric field. Specific calculations are given for a zero temperature gas and for classical high temperatures. Discussed briefly was the "dielectric screening" as induced by a magnetized electron gas. The Green's functions equation of motion for the "spin magnetization" was obtained. Brief mention is made of diagrammatic techniques.

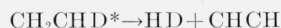
**Mechanism of the photolysis of ethane at 1470 Å.** R. F. Hampson, Jr., J. R. McNesby, H. Akimoton, and I. Tanaka, *J. Chem. Phys.* **40**, No. 4, 1099–1105 (Feb. 15, 1964).

A complete analysis of the products of the photolysis of ethane at 1470 Å has been carried out. Isotopic analyses of products of the photolysis of  $C_2H_6 + C_2D_6$  and of  $CH_3CD_3$  have led to the following conclusions.

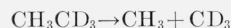
1. It is possible to explain the data on the basis that nearly all molecular hydrogen produced in the primary process comes from the end carbon atom.



The HD can be accounted for by the decomposition of excited  $CHD CD_2^*$  and  $CH_2CHD^*$ .



2. Other primary processes are



The importance of the latter, relative to the molecular elimination, is about 15:85.

3. Propane and butane arise from ethyl radicals formed by addition of H and D atoms to ethylene.

4. The excited state of ethane has a lifetime smaller than  $10^{-8}$  seconds.

**Continuum theory of a plasma**, J. L. Jackson and L. S. Klein, *Phys. Fluids* **7**, No. 2, 232-241 (Feb. 1964).

A continuum description of a classical plasma in equilibrium is presented. Thermodynamic properties and equilibrium fluctuations are discussed in terms of the fluctuations of the net charge density function  $n(r)$ . The probability distribution function of the potential at a typical point, and the joint distribution of the potential at two points are calculated. As was noted in the preceding paper, these results lead to the chemical potential and two-particle distribution function of classical Debye-Hückel theory. A first order correction to the potential distribution of the continuum theory is obtained by treating the nearest neighbor charge as a discrete charge and the remainder of the plasma as a continuum. The corresponding correction to the free energy is obtained and compared with the results of diagrammatic calculations, to which the present results are similar.

**Pressure broadening of DCl by HCl and of HCl by DCl. A comparison of experimental results with Anderson's theory**, T. C. James and R. J. Thibault, *J. Chem. Phys.* **40**, No. 2, 534-540 (Jan. 15, 1964).

Line widths in the 1-0 band of DCl broadened by HCl and in the 1-0 band of HCl broadened by DCl are reported for rotational levels up to  $|m|=15$  and 13, respectively. These experimental results are compared with calculated values using Anderson's theory as amplified by Tsao and Curnutte. Calculations are made at 300 °K for quadrupole moments of 2, 4, and 6 Debye angstroms and calculations at 194.5 °K are also made for a  $Q$  of 6 Debye angstroms.

**Energy losses and elastic resonances in electron scattering from  $H_2$** , C. E. Kuyatt, S. R. Mielczarek, and J. A. Simpson, *Phys. Rev. Letters* **12**, 293 (1964).

Recently developed techniques of high-resolution spectroscopy have been applied to molecular hydrogen. Inelastic scattering measurements for the first time show well resolved vibrational levels of several electronic states of  $H_2$ . Elastic scattering measurements show at least eight narrow resonances in the elastic cross section.

**Intensity of the forbidden  $X^2\Pi_{3/2}-X^2\Pi_{1/2}$  satellite bands in the infrared spectrum of nitric oxide**, T. C. James, *J. Chem. Phys.* **40**, No. 3, 762-771 (Feb. 1, 1964).

Satellite lines in the spectrum of nitric oxide which correspond to transitions  $^2\Pi_{1/2}$ ,  $v=0$ ,  $J \rightarrow ^2\Pi_{3/2}$ ,  $v=1$ ,  $J^1$  were observed. Intensities were measured and found to be in agreement with the theoretical predictions. Frequency measurements and line width measurements are also reported. A value for the intensity of the fundamental of  $138\text{ cm}^{-2}/\text{atm}$  at 273°K has been obtained.

**Energy spectra and angular distribution of electrons transmitted through sapphire ( $Al_2O_3$ ) foils**, M. J. Berger and S. M. Seltzer, *Natl. Aero. Space Admin. Spec. Publ. SP3008*, p. 1-107 (1964).

Monte Carlo results are presented, in the form of 72 tables, pertaining to the transmission of electrons incident with energies of 1, 2, 2.954, 4, 5.907 and 8 Mev on sapphire foils with thicknesses of 0.1, 0.2 and 0.3 g/cm<sup>2</sup>. Two types of beam geometry are treated for all source energies: (a) perpendicular incidence; (b) beams with an initial cosine-law angular distribution (corresponding to an isotropic electron flux). For a source energy of 2 Mev, various incident beam obliquities are also treated, ranging from grazing to perpendicular incidence. The physical factors taken into account include the energy losses due to collisions with atomic electrons (mean value and fluctuations), the mean energy loss due to bremsstrahlung, and the angular deflections and path detours due to multiple Coulomb scattering by atoms.

**Effects of anharmonicity on vibrational energy transfer**, F. H. Mies, *J. Chem. Phys.* **22**, No. 2, 523-531 (Jan. 15, 1964).

Certain diagonal matrix elements which enter into the quantum theory of vibrational energy transfer generally have been assumed to be identical. If Morse potentials are used to describe the molecular forces, the elements are approximately but not identically equal. The transition probability is found to decrease markedly when the ratio of the diagonal elements is allowed to deviate even slightly from one. Morse potentials were chosen to reproduce the observed anharmonicities of a variety of diatomic molecules and an anharmonic correction factor was calculated. It is found that the generally used transition probabilities should be reduced by a factor of the order of  $10^{-1}$ - $10^{-2}$ .

**High-resolution infrared determination of the structure of carbon suboxide**, W. J. Lafferty, A. G. Maki, and E. K. Plyler, *J. Chem. Phys.* **40**, No. 1, 224-229 (Jan. 1, 1964).

High-resolution spectra have been obtained and the vibration-rotation absorption spectrum has been analyzed for a  $\Sigma_u-\Sigma_g$  and a  $\Pi_g-\Pi_u$  transition in  $C_3O_2$  between  $3142\text{ cm}^{-1}$  and  $3195\text{ cm}^{-1}$ . The absorption region studied contains a parallel combination band and a series of associated "hot bands." The successive "hot bands" are displaced toward high frequencies in such a manner that the  $\Sigma-\Sigma$  and  $\Pi-\Pi$  bands are relatively free of overlapping lines. The analysis shows that the molecule must have  $D_{\infty h}$  symmetry with  $B_0 = 0.073206\text{ cm}^{-1}$ . The large number of "hot bands," their variation with temperature, and the large value of the  $l$ -doubling constant  $q$  all indicate that the lowest frequency bending mode must lie at quite low wave numbers.

**Infrared spectra and the structures and thermodynamics of gaseous  $LiO$ ,  $Li_2O$ , and  $Li_2O_2$** , D. White, K. S. Seshadri, D. F. Dever, D. E. Mann, and M. J. Linevsky, *J. Chem. Phys.* **39**, No. 10, 2463-2473 (Nov. 15, 1963).

The vapor above heated lithium oxide ( $Li_2O$ ) has been investigated mass spectrometrically and by infrared matrix-isolation spectroscopy. The vapor composition and Knudsen effusion rates were measured as functions of temperature, and the matrix spectra of the principal lithium oxide species— $Li_2O$ ,  $LiO$ ,  $Li_2O_2$ —identified and analyzed for different isotopic abundances. The predominant vapor species  $Li_2O$  is probably linear with  $r(Li-O) = 1.59\text{ Å}$ , and has fundamentals  $\nu_1$ ,  $\nu_2$ ,  $\nu_3$  at  $[760]$ ,  $[140]$ , and  $987\text{ cm}^{-1}$ , respectively. Its heat of formation  $\Delta H_0^\circ(f) = -43.7 \pm 2.5\text{ kcal/mole}$ . The diatomic molecule  $LiO$  has  $\nu = 745\text{ cm}^{-1}$ , and estimated bond length  $r = 1.62\text{ Å}$ , and  $\Delta H_0^\circ(f) = +16.0 \pm 5\text{ kcal/mole}$ . The previously undetected molecule  $Li_2O_2$  is shown to resemble the alkali halide dimers in having a planar rhombic ( $V_h$ ) structure for which the  $O-Li-O$  angle and  $Li-O$  bond length are estimated to be  $116^\circ$  and  $1.90\text{ Å}$ , respectively. Its  $B_{2u}$  and  $B_{3u}$  frequencies are found at  $324$  and  $522\text{ cm}^{-1}$ , respectively, in a krypton matrix. The remaining unobserved modes are estimated in  $\text{cm}^{-1}$  as follows:  $\nu_1(A_g) = 400$ ,  $\nu_2(A_g') = 250$ ,  $\nu_3(B_{1g}) = 300$ ,  $\nu_4(B_{1u}) = 270$ . Its  $\Delta H_0^\circ(f) = +27.5 \pm 6\text{ kcal/mole}$ .

**Exact conditions for the preservation of a canonical distribution in Markovian relaxation processes**, H. C. Andersen, I. Oppenheim, K. E. Shuler, and G. H. Weiss, *J. Math. Phys.* **5** No. 4, 522-536 (Apr. 1964).

Necessary and sufficient conditions have been determined for the exact preservation of a canonical distribution characterized by a time dependent temperature (canonical invariance) in Markovian relaxation processes governed by a master equation. These conditions, while physically realizable, are quite restrictive so that canonical invariance is the exception rather than the rule. For processes with a continuous energy variable, canonical invariance requires that the integral master equation is exactly equivalent to a Fokker-Planck equation with linear transition moments of a special form. For processes with a discrete energy variable, canonical invariance requires, in addition to a special form of the level degeneracy, equal spacing of the energy levels and transitions between nearest neighbor levels only. Physically, these con-

ditions imply that canonical invariance is maintained only for weak interactions of a special type between the relaxing subsystem and the reservoir. It is also shown that canonical invariance is a sufficient condition for the exponential relaxation of the mean energy. A number of systems (hard sphere Rayleigh gas, Brownian motion, harmonic oscillators, nuclear spins) are discussed in the framework of the above theory. Conditions for approximate canonical invariance valid up to a certain order in the energy are also developed and then applied to nuclear spins in a magnetic field.

**Changes in relation between refractive index and Young's modulus as the result of successive heat treatments**, E. H. Hamilton, *J. Am. Ceram. Soc.* **47**, No. 4, 167-170 (Apr. 1964). The relation between refractive index and elastic modulus is found to be a sensitive indicator of the nucleation and separation of submicroscopic phases in glass. While studying the changes in properties with heat treatments of a wide variety of glasses containing  $\text{SiO}_2$ ,  $\text{B}_2\text{O}_3$  and  $\text{ZnO}$  as major constituents, large decreases in Young's moduli were observed that were not accompanied by decreases in refractive indices of the magnitude usually observed. The abnormal changes in properties were the result of a sequence of two heat-treatments. The results indicate that during the first heat-treatment an immiscible phase is nucleated which on subsequent heat-treatment at a higher temperature develops into heterogeneous regions producing the changes in the refractive index versus elastic modulus relation.

**Calorimetry of portland cement. I. Effects of various procedures on determination of heat of solution**, H. A. Berman and E. S. Newman, *ASTM Proc.* **63**, 830-851 (1963). Nine calculation procedures for correcting the observed temperature rise in a solution calorimeter are compared. Eight of these procedures are used in various specifications for determining the heat of hydration of hydraulic cements by the heat-of-solution method.

The best reproducibility was found with methods that use long rating periods and reading intervals rather than short ones, that use constants of stirring energy and heat leakage that are independently calculated from calibrations or other pertinent tests of the apparatus or that are obtained in part from temperatures of the initial rating period rather than from temperatures of the final rating period (provided that they are accurately obtained), and that are not restricted by definitely specified duration times for the solution and rating periods. The best accuracy was found in methods that employ solution periods longer than 20 min and in methods that employ the most rigorous possible approach to the heat-leakage integration calculation consistent with the data available.

**Calorimetry of portland cement. II. Application of various heat-of-solution procedures to determination of heat of hydration**, E. S. Newman and H. A. Berman, *ASTM Proc.* **63**, 852-860 (1963).

The heats of hydration of two cement samples were determined using three types of heat-of-solution calorimeter. The three calorimeters were the ASTM standard air-bath Dewar, a submerged Dewar with a metal cover, and a submerged metal precision calorimeter using a resistance thermometer. The data were taken in sufficient detail to permit the computation of the corrected temperature rise by eight different methods, all based on Newton's law of cooling, recommended by various authorities in the United States and abroad. The determinations were made in two different rounds of duplicates, and the accuracy and precision of the calorimeters and of the methods are discussed on the basis of the results obtained. Differences among the calorimeters and methods found in heat-of-solution determinations largely disappeared in computing the heats of hydration. By the most rigorous method, standard deviations of 1.45, 1.38, and 0.70 cal/g were found for the heat of hydration as determined by the air-bath Dewar, the submerged Dewar, and the precision calorimeter, respectively.

**Relative oscillation strengths of some O II and O III lines from measurements on shock-heated plasmas**, H. F. Berg,

K. L. Eckerle, R. W. Burris, and W. L. Wies, *Astrophys. J.* **139** No. 2, 751-757 (Feb. 15, 1964).

The layer of plasma behind reflected shock waves, which were produced in a T-tube filled with a helium-oxygen mixture, served as a high-temperature light source for the measurement of relative oscillator strengths of some O II and O III lines. Densities and temperatures were determined using the line-broadening data of some neutral and ionized helium lines as well as their relative intensities. Some relative O II and O III oscillator strengths were then determined by intensity measurements, using a scanning technique. The O II results compared very well with previous work employing a high-current arc. Furthermore, for all measured oscillator strengths, theoretical values were obtained from the Coulomb approximation. The relative values from theory and experiment were found to be in satisfactory agreement. Absolute O III oscillator strengths could not be given with certainty due mainly to the rapid time characteristics of the source which made the establishment of an equilibrium population in the second ionization stage of oxygen uncertain.

**The crystallography of some  $\text{M}^{2+}$  borates**, S. Block, A. Perloff, and C. E. Weir, *Acta Cryst.* **17** Pt. 3, 314-315 (Mar. 1964).

Crystallographic information is presented for  $\text{BaO} \cdot 2\text{B}_2\text{O}_3$ ,  $\text{SrO} \cdot 2\text{B}_2\text{O}_3$ ,  $\text{PbO} \cdot 2\text{B}_2\text{O}_3$ ,  $\text{SrO} \cdot \text{B}_2\text{O}_3$  and  $\text{BaO} \cdot \text{B}_2\text{O}_3$ . All constants are presented. A short discussion of the structures of  $\text{BaO} \cdot 2\text{B}_2\text{O}_3$  and  $\text{SrO} \cdot 2\text{B}_2\text{O}_3$  is also given. The powder patterns of  $\text{SrO} \cdot 2\text{B}_2\text{O}_3$  and  $\text{PbO} \cdot 2\text{B}_2\text{O}_3$  are given.

**Theory of the electronic susceptibilities of stoichiometric rutile ( $\text{TiO}_2$ )**, A. R. Ruffa, *Phys. Rev.* **133**, No. 5A, 1418-1426 (Mar. 2, 1964).

A theoretical analysis of the symmetry properties of crystalline rutile is made leading to the conclusion that the isotropic solution of the local field equations for this material is correct. It is shown that this conclusion is supported by the experimentally determined isotropic nature of the magnetic susceptibility of rutile. The isotropic solution of the local field equations yields a value for the electronic polarizability of the titanium ion in rutile of  $\alpha_T = 2.7 \text{ \AA}^3$ , an order of magnitude greater than the free ion values usually assigned to the  $\text{Ti}^{4+}$  ion.

This result is supported by a correlation of the ionic sizes as obtained from an electron density map of rutile determined by x-ray analysis with the polarizabilities in a manner described previously. Moreover, this conclusion is in reasonably good quantitative agreement with a theoretical prediction made previously of the effect of the crystalline potential on the cation polarizability.

The results of this study give a specific example of a conclusion arrived at in an earlier work to the effect that a cation polarizability in a crystal may be many times its free ion value. Moreover, it demonstrates the unreliability of the usually accepted additivity rule for the ionic radii.

**The electrolysis of formamides, acetamides and propionamides**, D. E. Couch, *Electrochem. Acta* **9**, No. 4, 327-336 (Apr. 1964).

Solid products were produced by the electrolysis of *N*-methyl amides, and *N*, *N*-dimethylamides. The products are of two general classes, i.e., bis-amides of methane ( $\text{C}_n\text{H}_{2n}\text{M}_2\text{O}_2$ ) or bis-amides of methyl ether ( $\text{C}_n\text{H}_{2n}\text{N}_2\text{O}_3$ ). These products show that it is the groups or atoms attached to the nitrogen that enter into the electrolytic reaction, and that the methyl groups are more susceptible to electrolytic change than is hydrogen when both are attached to the same nitrogen atom.

**A review of photodetachment and related negative ion processes relevant to aeronomy**, L. M. Branscomb, *Ann. Geophys.* **20**, 88-102 (Jan.-Mar. 1964).

Taking the interpretation of the mechanism for Polar Cap Absorption as an illustration of the importance of negative ion reactions in aeronomy, processes for negative ion formation, destruction and rearrangement (other than recombination with positive ions) are reviewed. When possible cross sections, rate coefficients and binding energies are given. The models used in the interpretation of negative ion-effects



in PCA and Auroral Absorption events are criticized and several possible mechanisms are discussed.

**Microwave studies of butadiene derivatives. II. Isoprene.** D. R. Lide, Jr., and M. Jen, *J. Chem. Phys.* **40**, No. 1, 252-253 (Jan. 1, 1964).

The microwave spectrum of fluoroprene,  $\text{H}_2\text{C}=\text{CH CF}=\text{CH}_2$  has been previously studied in this laboratory. The isoprene molecule, in which the fluorine atom is replaced by a  $\text{CH}_3$  group, shows a very similar spectrum except for uniformly lower intensities. A number of b-type transitions in the 20-30 kmc region have been measured and assigned to the ground vibrational state of isoprene. The observed and calculated rigid-rotor frequencies are listed in Table I. No attempt was made to obtain a systematic assignment of vibrational satellite lines because of the weakness of the spectrum. As in the case of fluoroprene, no evidence for another isomer was found.

**Effects of tensile stress on the domain structure in grain-oriented 3.25% silicon.** J. J. Gniewek, *J. Appl. Phys.* **34**, No. 12, 3618-3622 (Dec. 1963).

A Kerr magneto-optic apparatus has been used to observe the effects of an electrical current and tensile stress on the domain structure in commercial, 3.25% silicon steel. Photographs are presented showing that it is possible, under certain conditions, for an electrical current to have a significant effect on the domain structure. This should be considered in elasto-resistance and low field magnetoresistance experiments. Upon application of a tensile stress of only 0.57 KG/mm<sup>2</sup>, a domain pattern resembling the 'lozenge' pattern is shown to occur in certain grains. The corresponding strain-free pattern is identified here as a 'chevron' pattern. From observations on the type of domain structure changes resulting from stress, it is concluded that in grains where the [001] direction tilts out of the surface plane by 4 to 8 degrees, the wall energy of the reverse domains and the surface pole energy combined make a significant contribution to the total crystal energy in .012" thick material.

### Other NBS Publications

**J. Res. NBS 68B (Math. and Math. Phys.), No. 3 (July-Sept. 1964), 75 cents.**

Generation and composition of functions. A. J. Goldman. Thermodynamics of perfect elastic fluids. B. Bernstein, E. A. Kearsley, and L. J. Zapas. (See above abstracts.) Zeros of polynomials in several variables and fractional order differences of their coefficients. B. Mond and O. Shisha. Theory of radiation from sources immersed in anisotropic media. J. R. Wait. (See above abstracts.)

**J. Res. NBS 68C (Eng. and Instr.), No. 3 (July-Sept. 1964), 75 cents.**

Response of highly precise balances to thermal gradients L. B. Macurdy. (See above abstracts.) A direct-reading two-knife 50-pound balance of high precision suitable for State weights and measures laboratories. H. E. Almer, H. A. Bowman, M. W. Jensen, L. B. Macurdy, H. S. Peiser, and B. Wasko. Wave front shearing prism interferometer. J. B. Saunders. A new high resolution small-angle x-ray camera. H. Brumberger and R. Deslattes. (See above abstracts.) Experimental determination of air drag on a textile yarn struck transversely by a high-velocity projectile. J. C. Smith, C. A. Fenstermaker, and P. J. Shouse.

**Radio Sci. J. Res. NBS/USNC-URSI, 68D, No. 8, (Sept. 1964) \$1.00.**

Extension of cosmic noise absorption measurements to lower frequencies, using polarized antennas. C. G. Little, G. M. Lerfald, and R. Parthasarathy. Broadband radio-star scintillations, part I. Observations. D. G. Singleton. F-region irregularities studied by scintillation of signals from satellites. K. C. Yeh and G. W. Swenson, Jr. Angels, insects, and weather. A. H. LaGrone, A. P. Deam, and G. B. Walker.

Measurement of the attenuation of radio signals by jungles.

Jack W. Herbstreit and W. Q. Crichlow.

Influence of a circular ionospheric depression of VLF propagation. J. R. Wait.

An experimental study of mixed-path groundwave propagation. S. W. Maley and H. Ottesen.

**Radio Sci. J. Res. NBS/USNC-URSI, 68D, No. 9 (Sept. 1964), \$1.00.**

Symposium on Signal Statistics, Seattle, Washington, U.S.A., December 6-7, 1963:

Signal statistics, yesterday and today. F. L. H. M. Stumpers. Rayleigh distribution and its generalizations. P. Beckmann. Some nonlinear problems arising in the study of random processes. M. Rosenblatt.

An approach to empirical time series analysis. E. Parzen.

Effect of linear and nonlinear signal processing on signal statistics. A. V. Balakrishnan.

Random volume scattering. H. Bremmer.

Phase fluctuation statistics. J. B. Smyth.

Current topics in the stochastic theory of radiation. F. J. Zucker.

On the intensity distribution

$$\frac{2R}{\sqrt{\alpha\beta}} \exp \left[ -\frac{R^2}{2} \left( \frac{1}{\alpha} + \frac{1}{\beta} \right) \right] I_0 \left( \frac{R^2}{2} \left[ \frac{1}{\beta} - \frac{1}{\alpha} \right] \right)$$

and its application to signal statistics. M. Nakagami. Statistical inference for Rayleigh distributions. M. M. Siddiqui.

A probabilistic approach to the problem of large antenna arrays. Y. T. Lo.

Influence of data processing on the design and communication of experiments. S. W. Golomb.

Spectral measurement techniques in planetary radar. G. Pettengill.

Quantum statistics and lasers. J. P. Gordon.

Statistics of random surfaces. I. Kay and P. Swerling.

Modified gaussian distributions for slightly nonlinear variables. M. S. Longuet-Higgins.

**Radio Sci. J. Res. NBS/USNC-URSI, 68D, No. 10 (Oct. 1964).**

Theoretical heights and durations of echoes from large meteors. L. A. Manning.

Experimental determination of meteoric line densities and attachment rates. L. A. Manning.

Broadband radio-star scintillations, II. Interpretation. D. G. Singleton.

Electron collision frequency in the ionospheric D region. R. F. Benson.

A discussion of the theory of ionospheric cross modulation. R. F. Benson.

Theory of a slotted-sphere antenna immersed in a compressible plasma. Part I. J. R. Wait.

Theory of a slotted-sphere antenna immersed in a compressible plasma. Part II. J. R. Wait.

Electromagnetic scattering coefficients for concentric spheres and the problem of interference free enclosures. R. A. Eldred, H. A. Lasitter, and J. Roberts.

Ionospheric sounding using coded pulse signals. D. C. Coll and J. R. Storey.

Measurement of the complex time-frequency channel correlation function. P. A. Bello.

The NBS standard hygrometer, A. Wexler and R. W. Hyland, NBS Mono. 73 (May 1, 1964), 30 cents.

Microstructure of ceramic materials, Proceedings of an American Ceramic Society Symposium, Pittsburgh, Pa., April 27-28, 1963, NBS Misc. Publ. 257 (Apr. 6, 1964), \$1.75.

Physical aspects of irradiation, Recommendations of the International Commission on Radiological Units and Measurements, NBS Handb. 85 (Mar. 31, 1964), 70 cents. (Supersedes parts of H78. Handbooks 84 through 89 extend and largely replace H78.)

- Vinyl-coated glass fiber insect screening and louver cloth, NBS CS248-64 (Feb. 17, 1964), 10 cents.
- Shoeboard, CS260-63 (Sept. 10, 1963), 10 cents.
- Structural insulating board (wood or cane fiber), NBS R179-63 (Dec. 23, 1963), 10 cents. (Supersedes R179-56.)
- Correction factor tables for four-point resistivity measurements on thin, circular semiconductor samples, L. J. Swartzendruber, NBS Tech. Note 199 (Apr. 15, 1964), 30 cents.
- The normal phase variations of the 18 kc/s signals from NBA observed at Maui, Hawaii, A. H. Brady, A. C. Murphy, and D. D. Crombie, NBS Tech. Note 206-2 (Mar. 19, 1964), 25 cents.
- The normal phase variations of the 18 kc/s signals from NBA observed at Boulder, Colorado, U.S.A., A. H. Brady, A. C. Murphy and D. D. Crombie, NBS Tech. Note 206-3 (Apr. 10, 1964), 25 cents.
- Quantum field theoretic techniques and the electromagnetic properties of a uniformly magnetized electron gas, L. A. Steinert, NBS Tech. Note 207 (Apr. 6, 1964), \$1.50.
- A portable rubidium-vapor frequency standard, R. J. Carpenter, NBS Tech. Note. 235 (Apr. 6, 1964), 25 cents.
- Research on crystal growth and characterization at the National Bureau of Standards, July to December 1963, ed. H. S. Peiser, NBS Tech. Note 236 (Apr. 6, 1964), 40 cents.
- Disclosures on various subjects: A frequency meter, a phase shifter, a double-tuned transformer, and a ram-controlled system, NBS Tech. Note 237 (Apr. 10, 1964), 15 cents.
- Miscellaneous studies in probability and statistics: distribution theory, small-sample problems, and occasional tables, The Statistical Engineering Laboratory, NBS Tech. Note 238 (Apr. 24, 1964), 20 cents.
- Average power dissipated in a diode swept along its reverse characteristic, H. A. Schafft, NBS Tech. Note 240 (Apr. 30, 1964), 20 cents.
- Conference on non-linear processes in the ionosphere December 16-17, 1963, Ed. D. H. Menzel and E. K. Smith, Jr., NBS Tech. Note 211, Vol. 2 (Apr. 17, 1964); Vol. 3 (Apr. 19, 1964); Vol. 4 (Apr. 22, 1964); Vol. 5 (Apr. 24, 1964); and Vol. 6 (Apr. 24, 1964), 45 cents each.
- Bolometric microwave power calibration techniques at the National Bureau of Standards, R. F. Desch and R. E. Larson, IEEE Trans. Instr. Meas. **1M-12**, No. 1, 29-33 (June 1963).
- Potential distribution method in equilibrium statistical mechanics, J. L. Jackson and L. S. Klein, Phys. Fluids **7**, No. 2, 228-231 (Feb. 1964).
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